

CHARACTERIZING MULTI-KICK BEAM ORBIT MODELS using BMAD-TAO for improved model accuracy and accelerator beam dynamics adjustment control

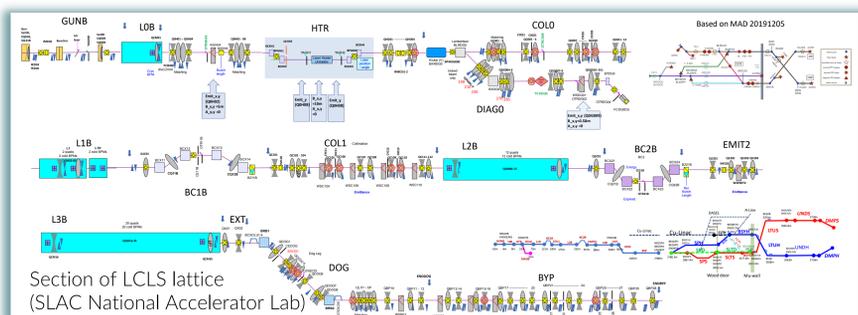
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BACKGROUND

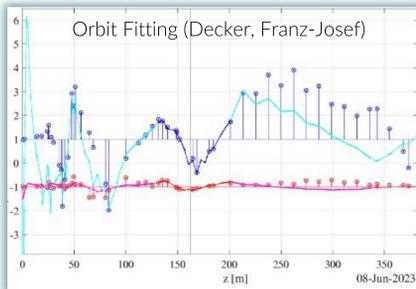
- **Beam orbit dynamics** – behavior and trajectory of charged particle beams
- Beam orbit model allows for predictions and calculations of measured beam performance, improving beam prediction, diagnostics, and optimizations



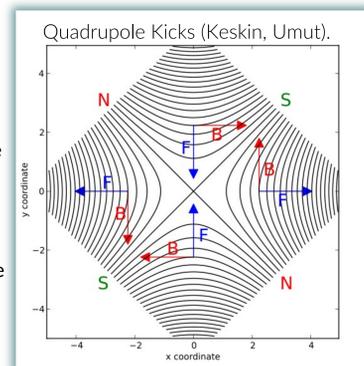
- **Beam Positioning Monitors (BPMs)** track the position of particles
- This data provides information on the particle's trajectory, which is used for maintaining beam path

INTRODUCTION

- Existing beam orbit models can only cover one kick, which limits the understanding of complex beam dynamics



- **Kicks** - sudden changes in a particle beam's trajectory and momentum
- This can occur in both x and y orbits, including with coupling
- **Coupling** - disturbances in one plane, horizontal or vertical, affects the dynamic of the other plane, including energy transferring
- Small rotation errors can cause quadrupole to kick in both planes instead of one, causing the coupling effect on the beam

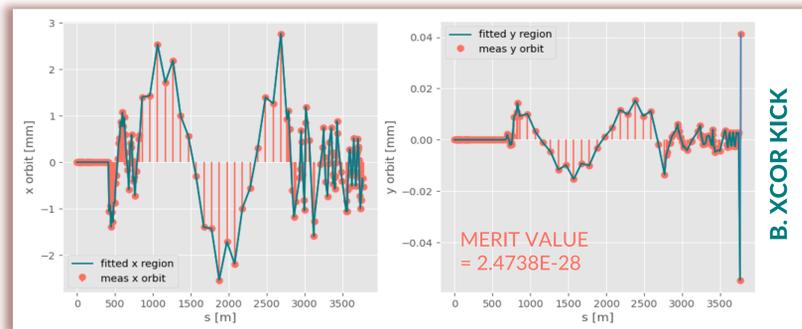
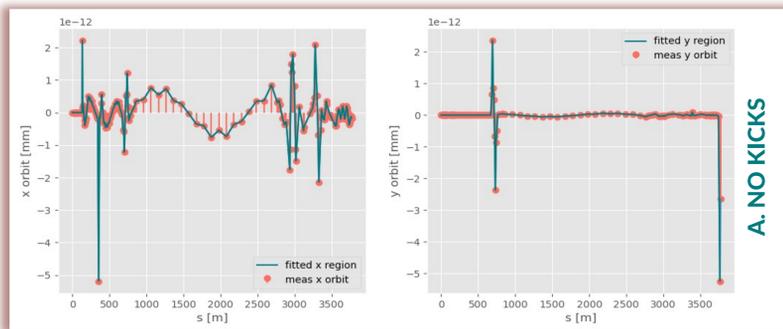


- **Bmad** and **TAO** (Tool for Accelerator Optics) simulates/optimizes beam dynamics
 - **Data:** $\delta D = model_{data} - meas_{data}$ **Variables:** $\delta V = model_{variable} - meas_{variable}$
 - **Merit Function** quantifies the goodness of fit of the model; Merit Function = $w_D \cdot (\delta D)^2 + w_V \cdot (\delta V)^2$
- Goal:** Use Bmad-TAO to multi-kick beam orbits, allowing for the matching and fitting of experimental data with realistic physics-based tracking.

METHODS/RESULTS

TAO MODEL

1. Create synthetic measurement data by adding kicks. Note: can add more characteristics to kicks using Bmad, and we can select as many BPMs in a region as we want. `tao.set_ele_XCM16_BL_KICK = 0.0005'`
2. Run TAO Optimization. Variables: kicks defined in kickFit array structure, with characteristics such as adjustment step size, value limits, etc.

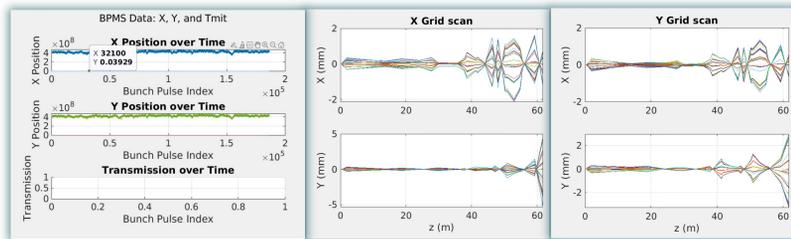


XCOR: XCM16/X Corrector Magnet 16; YCOR: YCM22/Y Corrector Magnet 22; QUAD: QCM18/Quadrupole Magnet 18; CAVL kicks not depicted

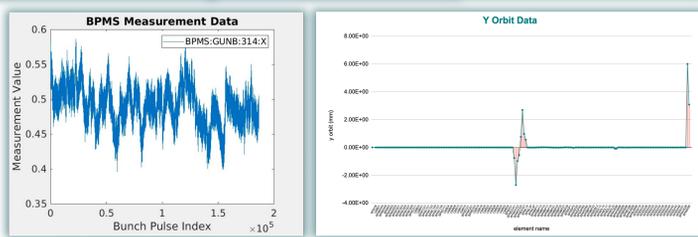
MACHINE-BASED FITTING

Parse oscillation data: `/mccfs2/u1/lcls/matlab/data/2025/2025-07/2025-07-08/OnlineMonitor-orbitSearchSynch-BSA-2025-07-08-16-59-05-765.mat`

Scalars: [186561 x 603 double]
ScalarsList: {603 x 1 cell}
SynchInfo: [1 x 1 struct]

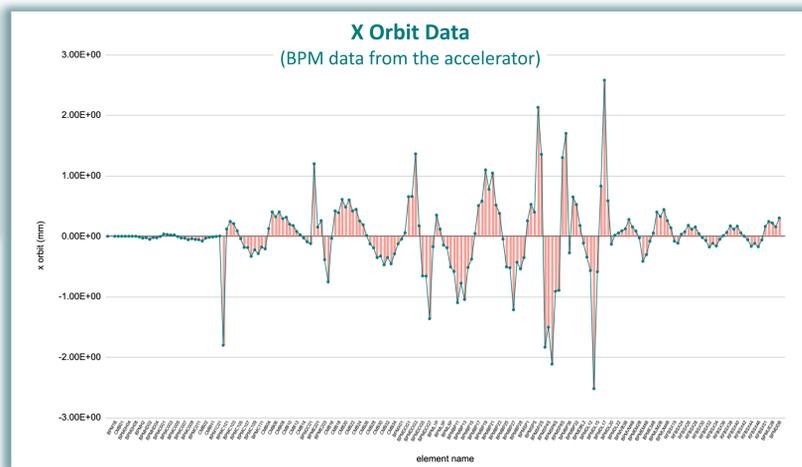
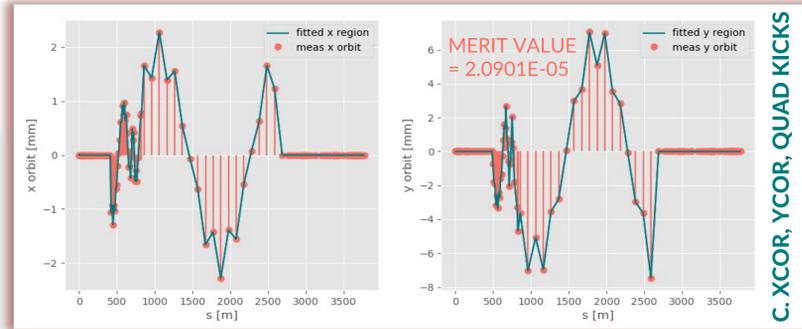


1. Isolate BPM data into PVLlist (Process Variable List)
2. Load PVLlist into lattice on TAO using reference orbit
3. Test model characterizations on BPM measured data sections, measuring accuracy and precision of the Bmad/TAO orbit fitting method (in progress, to be continued)



RESULTS ANALYSIS

- No-kick lattice design orbit graph has significantly different datapoints and orbits in comparison to the measurements taken from the beam position monitors in the accelerator—showing that accurate modeling is necessary for beam control
- Synthetic kicking tests (singular and multiple up to four kicks, not pictured) have all reached merit values below 5.00E-05
 - Merit values decrease as the amount of kicks increase, but accurately models orbits even with inaccurate kick sets
- Usage of Bmad allows fitting BPM misalignments (X and Y OFFSET), QUAD focusing errors, QUAD misalignments (X and Y OFFSET, TILT, and others)
 - TILT errors will lead to X/Y coupling as shown in machine data (pure X orbit shows Y response in some plots)
- Future research will be continued on the applications of such Bmad/TAO orbit fit models onto machine BPM data



ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to my mentor William Colocho for his guidance and support throughout this internship and with my project. I'd like to also thank Franz-Josef Decker for teaching me orbit fittings. Bmad/TAO was developed by the CLASSE team at Cornell, and I'd like to thank David Sagan, Georg-Hoffstaetter de Torquat, and J. Scott Berg for teaching me Bmad/TAO. Lastly, I'd like to give a special thanks to Alan Fry, Arturo Garcia, Hillary Freeman for organizing and hosting the LCLS Intern program, making this experience possible.

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